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FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371	ATTORNEY'S DOCKET NUMBER **7604/21/1** U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR **10/069696**

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/US00/23057	**23 August 2000**	**23 August 1999**

TITLE OF INVENTION
Method and Apparatus for Remote Measurement of Vibration and Properties of Objects

APPLICANT(S) FOR DO/EO/US
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Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☒ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

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U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/069696	INTERNATIONAL APPLICATION NO. PCT/US00/23057	ATTORNEY'S DOCKET NUMBER 7604/21/1

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1040.00**

☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$890.00**

☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**

☒ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**

☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				**$710.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				**$130.00**	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	43 - 20 =	23	x $18.00	**$414.00**	
Independent claims	4 - 3 =	1	x $84.00	**$84.00**	
Multiple Dependent Claims **(check if applicable)**.			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$1,338.00**	
☒ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$669.00**	
SUBTOTAL =				**$669.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$669.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$669.00**	
				Amount to be: refunded	$
				charged	$

a. ☐ A check in the amount of ____________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. **06-2143** in the amount of **$669.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **06-2143** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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METHOD AND APPARATUS FOR REMOTE MEASUREMENT OF VIBRATION AND PROPERTIES OF OBJECTS

SPECIFICATION

BACKGROUND OF THE INVENTION

FIELD OF INVENTION

The present invention generally relates to a method and apparatus for nondestructive testing, monitoring of technological processes, determining structural integrity, noise and vibration control, and mine detection. More specifically, the present invention relates to a phase-amplitude modulated electromagnetic wave (PAM-EW) vibrometer.

RELATED ART

Existing remote vibrometers are generally based on coherent laser generated signals. These devices, known as laser-doppler vibrometers, require precision and expensive optical elements (acousto-optic modulators, gas lasers, mirrors, beam splitters, etc.) A very precise, very coherent source is required, i.e. very stable phase characteristics. Fine adjustments are necessary to achieve a desirable effect. As a result, the laser-doppler vibrometers are quite expensive and delicate instruments are best suited for laboratory use.

Another serious drawback of the conventional remote sensing devices is their high sensitivity to unwanted vibration of the transmitting/receiving assembly (TRA). In fact, vibrometers measure only relative velocity/displacement between the vibrating object and the TRA. Since the sensitivity of the conventional laser-doppler vibrometers is very high it is very difficult to isolate the TRA from such small vibrations especially under field conditions. In addition to this, conventional vibrometers are susceptible to so-called cosine error. That is, if the incident electromagnetic wave is not precisely perpendicular to the irradiated surface, an error proportional to the cosine of the angle between the line of radiation and a normal to the surface is introduced.

Efforts of others in this area include U.S. Patent No. 5,883,715, to

Steinlechner, et al., entitled Laser Vibrometer for Vibration Measurements; U.S. Patent No. 5,897,494, to Flock, et al., entitled Vibrometer; U.S. Patent No. 5,495,767, to Wang, et al., entitled Laser Vibrometer; and U.S. Patent No. 4,768,381, to Sugimoto, entitled Optical Vibrometer.

None of these efforts of others teaches or suggests all of the elements of the present invention, nor do they disclose all of the advantages of the present invention.

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a phase-amplitude modulated electromagnetic wave (PAM-EW) vibrometer.

It is an additional object of the present invention to provide a method and apparatus for measuring vibration of a vibrating object which uses a modulated electromagnetic probing wave, wherein the vibration of the vibrating object additionally modulates the modulated probing wave.

It is another object of the present invention to provide a vibrometer which uses an optical source which is not necessarily coherent, for example, an LED source.

It is even an additional object of the present invention to provide an additional set of acoustic transmitters/receivers attached directly to the electromagnetic wave transducer assembly to enhance performance.

These and other objects of the present invention are achieved by a method and apparatus which employs phase or amplitude modulated electromagnetic probing waves (in optical or microwave frequency ranges or both) emitted toward a vibrating object. The optical and/or microwave probing signals remotely irradiate an object of interest. The object reflects and/or scatters the probing wave toward to a receiver. The reflected/scattered modulated signal is received with a remote sensor (receiver). Vibration causes additional phase modulation to the probing wave. At the receiving end, the signal is demodulated to extract and analyze vibration waveform. The invention also employs an innovative method and algorithm for enhanced performance of the vibrometer by using an additional set of acoustic transmitters/receivers attached directly to the electromagnetic wave transducer assembly. This additional set and corresponding data processing algorithm allow for compensation of the unwanted background (or coupled) vibration of the vibrometer and for calibrated measurements of the displacement of the vibrating object irradiated under an arbitrary angle. The method and apparatus of the present invention can be utilized for nondestructive testing, monitoring of technological processes, structural integrity, noise and vibration control, mine detection, etc.

The present invention can be used in connection with existing methods and apparatuses for detecting land mines and detecting defects in structures. Such

existing methods and apparatuses include U.S. Patent No. 5,974,881, dated November 2, 1999 to Donskoy, et al. and pending U.S. Application Serial No. 09/239,133, filed January 28, 1999 by Donskoy, et al., the entire disclosures of which are expressly incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

Other important objects and features of the present invention will be apparent from the following Detailed Description of the Invention taken in connection with the accompanying drawings in which:

FIG. 1 is a schematic view of the method and apparatus of the present invention.

FIG. 2 is a schematic view of the method and apparatus for compensating for errors arising from unwanted vibration of the transmitting/receiving assembly (TRA).

FIG.3a is a schematic view of an experimental set-up of the method and apparatus of the present invention.

FIG. 3b is a graph of the results of the experiment shown in FIG. 3a.

FIG. 4 is a schematic of a microwave vibrometer embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a method and apparatus which employs phase or amplitude modulated electromagnetic probing waves (in optical or microwave frequency ranges) emitted toward a vibrating object. This is shown schematically in **FIG. 1**. The apparatus is generally indicated at **10**. A signal is generated by the signal generator **12**, and then modulated by the modulating device **14** which receives a modulating signal from the modulating generator **16**. Preferably, the signal is amplitude modulated. The optical or microwave probing signals **20** are transmitted by transmitter **18** and remotely irradiate an object **8** of interest. The object **8** reflects and/or scatters the probing wave **20** toward to a receiver **22**, where it is received. Vibration of object **8** causes additional phase modulation to the probing wave **20**, based on the fact that object **8** is vibrating, which becomes amplitude/phase modulated signal **24**. At the receiving end, the signal **24** is demodulated by demodulation device **26**, according to signal processing system **28**, to extract and analyze vibration waveform.

The present invention can be used regardless of coherency of the emitting radiation, thus eliminating need in precision and expensive optical elements. A laser, or even a light emitting diode (LED) can be used as the source. The intensity is modulated at a very high frequency, for example in the GHz range. This results in significant cost reduction of the vibrometer.

The use of microwave radiation brings additional capabilities for the remote sensing, allowing for measurements of internal vibrations of the object due to penetrating capabilities of microwave radiation. The frequency of the microwave radiation can be the same as the modulating frequency of the optical signal, thus allowing for a shared use of electronic circuitry for both received microwave and optical signals.

The present invention also employs an innovative method and algorithm for enhanced performance of the vibrometer by using an additional set of acoustic transmitters/receivers attached directly to the electromagnetic wave transducer assembly. This additional set and corresponding data processing algorithm allow for compensation of the unwanted background, or coupled, vibration of the vibrometer

and for calibrated measurements of the displacement of the vibrating object irradiated under an arbitrary angle.

Referring to **FIG. 2**, the method and algorithm for compensating for cosine and transmitter/receiving assembly (TRA) 30 vibration errors, is shown. A 3D accelerometer **32** (or any motion sensor) and a CW (continuous wave) source **34** of vibration at frequency f_0, are attached to the TRA **30**. The 3D sensor **32** measures three components of the TRA vibration displacements: x(t), y(t), and z(t). The output of the TRA **30** is proportional to the variation in the length, L(t), between the TRA **30** and the surface of the tested object **8**. L(t) can be defined using **FIG. 2** geometry. For simplicity only the XZ-plate dependent (2D case) is considered:

$$L(t) = \xi(t)/\cos\Theta_{xz} + x(t)\sin\Theta_{xz}/ \cos\Theta_{xz} + z(t) \qquad (1)$$

where $\xi(t)$ is the normal displacement of the vibrating object, and Θ_{xz} is the angle between the normal to the surface of the object **8** and z-axes of the TRA **30**. Here x(t) and z(t) are unwanted components of the output signal. The signal z(t) can be easily compensated (subtracted) since it is directly measured with the 3D sensor **32**. However to compensate for x(t), the angle Θ_{xz} must be determined. This can be done using a CW vibration source **34**, which causes the TRA **30** to vibrate at a fixed frequency f_0 with amplitude A_{ox}. Taking this vibration into account, Eq.(1) can be re-written as:

$$L(t) - z(t) = [\xi(t)/\sin \Theta_{xz} + x(t) + A_{ox}\cos(2\pi f_0 t)]\tan \Theta_{x2}. \qquad (2)$$

By choosing the applied vibration large enough that $A_{ox} >> [\xi(t)/\sin \Theta_{xz} + x(t)]$, the output signal at the known frequency f_0 can be used to evaluate unknown angle Θ_{xz}:

$$L(t) - z(t)\big|_{f=f0} \cong A_{0x} \tan \Theta_{xz}. \qquad (3)$$

Thus, formula (3) can be used to evaluate the angle Θ_{xz} and knowing x(t) and z(t), which are measured with the 3D sensor **32**, the true displacement $\xi(t)$ can be determined using formula (1).

This algorithm can be easily extended for the 3D case, in which a vibrating source generates x and y components of vibration and the 3D sensor also measures the y component of the TRA vibration.

The apparatus of the present invention comprises an optical or microwave transmitter, corresponding receiver, and electronics including power supplies, signal generators, amplifiers, modulators, demodulators, acquisition and processing units.

FIG. 3a is a schematic view of an experimental setup of the present invention. A laser diode **40** is used as the source of light. One suitable laser diode is the Sharp LT-023, having a wavelength of 790 nm and 2 mW of power. Any other suitable light source can be used. Coherency of the light source is not too important, and accordingly, even and LED could be used. The laser diode **40** is powered by current source **42** which supplies current to drive the laser **40**. The current goes through a bias tee **44** which is an electronic scheme which allows for the modulation of the current supplied to the laser diode **40**. The current is modulated by the signal from signal generator **46**, at for example 250 kHz. However, for better results in practice, the modulating signal is in the GHz range, i.e. a few GHz or higher, because the device is more sensitive at higher frequencies. The intensity of the laser signal is thereby amplitude modulated.

The modulated signal **48** is then sent at the object **50**. The signal **48** is reflected or scattered by the object **50**, and the reflected signal **54** is received by photodetector **52**. In the experimental setup shown, the vibrating object **50** comprises a shaker and an accelerometer to make actual measurements of the vibration for comparison to experimental results. The reflected signal **54** received by the photodetector **52** is proportional to intensity. The amplitude modulated signal **48** is additionally modulated in phase by the vibration of the object **50** such that reflected signal **54** is amplitude and phase modulated. The reflected signal **54** is then amplified by amplifier **56** and fed to mixer **58** which also receives a signal from the signal generator **46**. The mixer **58** mixes these signals, the phase modulated signal and the reference signal to demodulate the reflected signal, which is sent to the spectral analyzer **60**.

FIG. 3b graphically shows the frequency response of the vibrating object measured by the laser of the present invention and as measured directly by the accelerometer. As can be seen, the present invention measures the vibration in accordance with measurements taken directly of a vibrating object. As the

modulating frequency is increased, the results become more accurate.

FIG. 4 is a schematic of a microwave vibrometer embodiment of the present invention. An oscillator or signal generator **60** generates a signal at, for example, 2.45 GHz. The signal is split by power splitter **62**. Part of the signal goes to mixer **76** where it will later be used. The other part of the signal is sent to amplifier **64** where it is amplified and then to circulator **66** and then to antenna **68** which sends signal **70** to vibrating surface **72** where it is reflected, scattered and modulated. Modulated signal **74** is also received by the antenna **68** and sent back to the circulator **66** which decouples the signal. This signal is then sent to amplifier **76** and then to mixer **82** which is part of a heterodyne scheme including second oscillator **78** which sends a signal at an intermediate frequency, for example 2.56 GHz, through power splitter **80** to mixer **82**. In this way, the reference signal and the reflected signal are not mixed directly, but rather each is mixed with an intermediate frequency, which provides advantages in terms of signal to noise ratio. The signal leaving the mixer **82** is the difference of 2.56 GHz and 2.45 GHz which is the intermediate frequency (IF) of 110 MHz. This signal is sent to low pass filter **84** and then to amplifier **86** and then to I&Q demodulator **88**. Mixer **76** receives signals from both oscillators **60** and **78** through power splitters **62** and **80** respectively, and sends them to low pass filter **90** and then through amplifier **92** to I&Q demodulator **88**. I&Q demodulator **88** functions essentially as a mixer which demodulates the signal into real and imaginary parts which correspond to amplitude and phase. These signals are sent through preamplifiers **94**, bandpass filters **96** and amplifiers **98**.

The present invention can be used as a remote sensing device used for various applications, including, but not limited to, nondestructive testing, characterization and monitoring of mechanical structures and civil structures (bridges, storage tanks, etc), air- and car-frames, pipes, pressure vessels, weldments, engines, etc.

Accordingly, the present invention provides a method and apparatus that relates to an electromagnetic wave vibrometer which generates an electromagnetic signal and transmits the signal at a vibrating object. A receiver for receiving a reflected or scattered phase modulated signal from the vibrating object is provided

and feeds the signal to a demodulator for demodulating the received signal and a signal processor for analyzing the vibration waveform. Additionally, a method and apparatus is provided for remotely measuring properties of an object including a signal generator for generating an electromagnetic signal and transmitting a signal at an object. A means for vibrating the object is provided. The vibrating object phase modulates the transmitted signal. A receiver picks up the reflected and scattered phase modulated signal and a demodulator demodulates the received signal and a signal processor analyzes the vibration waveform. Similarly, the present invention relates to methods for remotely measuring vibration and remotely determining properties of an object.

Having thus described the invention in detail, it is to be understood that the foregoing description is not intended to limit the spirit and scope thereof. What is desired to be protected by Letters Patent is set forth in the appended claims.

CLAIMS

What is claimed is:

1. An electromagnetic wave vibrometer apparatus comprising:

a signal generator for generating an electromagnetic signal;

a transmitter for transmitting the signal at a vibrating object;

a receiver for receiving a reflected and/or scattered phase modulated signal from the vibrating object;

a demodulator for demodulating the received signal; and

a signal processor for analyzing the vibration waveform of the demodulated signal.

2. The apparatus of claim 1 wherein the signal is an optical signal and the apparatus further comprises a modulator for amplitude modulating the optical signal to form an amplitude modulated signal.

3. The apparatus of claim 2 wherein the optical signal is amplitude modulated with a microwave frequency signal.

4. The apparatus of claim 1 wherein the signal is a microwave signal.

5. The apparatus of claim 1 wherein the signal is a combination of optical and microwave signals.

6. The apparatus of claim 5 wherein the optical signal is modulated by the same frequency as the transmitted microwave signal.

7. The apparatus of claim 1 further comprising a laser signal source.

8. The apparatus of claim 1 further comprising an LED signal source.

9. The apparatus of claim 1 further comprising a second vibration receiver mounted with the first receiver for compensation for unwanted background or coupled vibration.

10. The apparatus of claim 9 further comprising a second vibration transmitter mounted with the first receiver for calibration of the apparatus to determine angle of reflection.

11. An apparatus for remotely measuring properties of an object comprising:

a signal generator for generating an electromagnetic signal;

a transmitter for transmitting the signal at an object;

means for vibrating the object to phase modulate the signal transmitted at the object;

a receiver for receiving a reflected and/or scattered phase modulated signal from the object;

a demodulator for demodulating the received signal; and

a signal processor for analyzing the vibration waveform of the demodulated signal.

12. The apparatus of claim 11 wherein the signal is an optical signal and the apparatus further comprises a modulator for amplitude modulating the optical signal to form an amplitude modulated signal.

13. The apparatus of claim 12 wherein the optical signal is amplitude modulated with a microwave frequency signal.

14. The apparatus of claim 11 wherein the signal is a microwave signal.

15. The apparatus of claim 11 wherein the signal is a combination of optical and microwave signals.

16. The apparatus of claim 15 wherein the optical signal is modulated by the same frequency as the transmitted microwave signal.

17. The apparatus of claim 11 further comprising a laser signal source.

18. The apparatus of claim 11 further comprising an LED signal source.

19. The apparatus of claim 11 further comprising a second vibration receiver mounted with the first receiver for compensation for unwanted background or coupled vibration.

20. The apparatus of claim 19 further comprising a second vibration transmitter mounted with the first receiver for calibration of the apparatus to determine angle of reflection.

21. A method of remotely measuring vibration comprising:

generating an electromagnetic signal;

transmitting the signal at a vibrating object;

receiving reflected and scattered phase modulated signal from the vibrating object;

demodulating the reflected phase modulated signal; and

analyzing the demodulated signal.

22. The method of claim 21 wherein the signal is an optical signal and the method further comprises modulating the signal before transmitting the signal.

23. The method of claim 22 wherein the step of modulating the signal comprises amplitude modulation.

24. The method of claim 21 wherein the signal comprises a microwave signal.

25. The method of claim 21 wherein the signal comprises a combination of microwave and optical signals.

26. The apparatus of claim 25 wherein the optical signal is modulated by the same frequency as the transmitted microwave signal.

27. The method of claim 21 wherein the signal is generated by a laser or a low coherent laser diode.

28. The method of claim 21 wherein the signal is generated by an LED.

29. The method of claim 21 further comprising compensating for vibration errors by determining vibration displacements of the transmitter and receiver.

30. The method of claim 29 further comprising providing a second vibration receiver mounted with the first receiver for compensating for unwanted background or coupled vibration.

31. The method of claim 30 further comprising providing a second vibration transmitter mounted with the first receiver for calibrating of the vibrometer to determine angle of reflection.

32. A method for remotely determining properties of an object comprising:

transmitting a signal at an object:

vibrating the object;

receiving the reflected and scattered phase modulated signals from the vibrating object; and

processing the phase modulated signal to extract information about the properties of the object.

33. The method of claim 32 wherein the signal is an optical signal and the method further comprises modulating the signal before transmitting the signal.

34. The method of claim 33 wherein the step of modulating the signal comprises

amplitude modulation.

35. The method of claim 32 wherein the signal comprises a microwave signal.

36. The method of claim 32 wherein the signal comprises a combination of microwave and optical signals.

37. The apparatus of claim 32 wherein the optical signal is modulated by the same frequency as the transmitted microwave signal.

38. The method of claim 32 wherein the signal is generated by a laser or a low coherent laser diode.

39. The method of claim 32 wherein the signal is generated by an LED.

40. The method of claim 32 wherein the generated signal is split into first and second signals and the second signal is transmitted to a demodulator for comparing the second signal with the received reflected signal.

41. The method of claim 32 further comprising compensating for vibration errors by determining vibration displacements of the transmitter and receiver.

42. The method of claim 41 further comprising providing a second vibration receiver mounted with the first receiver for compensating for unwanted background or coupled vibration.

43. The method of claim 42 further comprising providing a second vibration transmitter mounted with the first receiver for calibrating of the vibrometer to determine angle of reflection.

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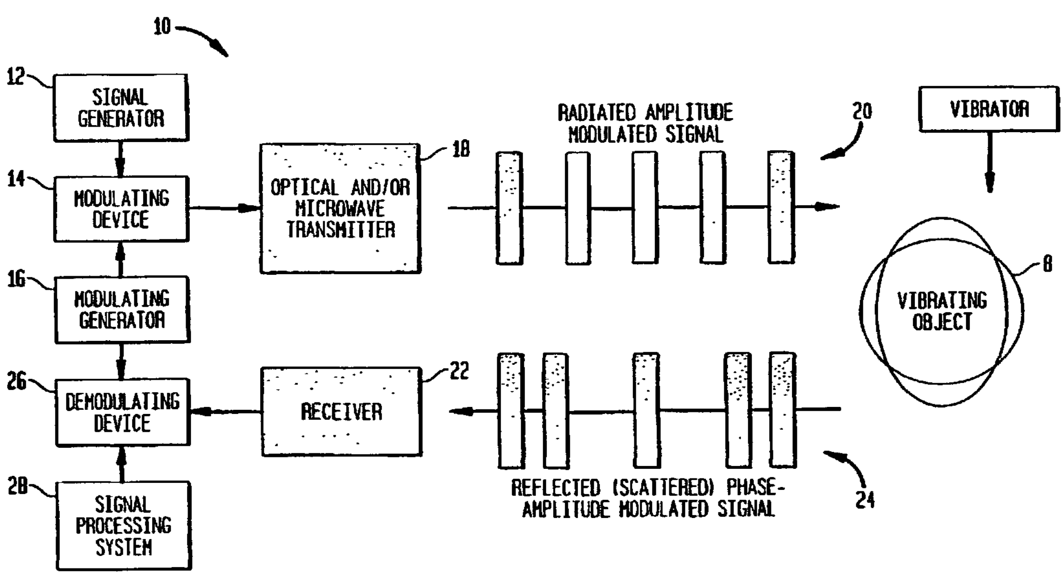
[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR REMOTE MEASUREMENT OF VIBRATION AND PROPERTIES OF OBJECTS



(57) Abstract: A method and apparatus (10) is provided which employs phase or amplitude modulated electromagnetic probing waves (20) (in optical or microwave frequency ranges or both) emitted toward a vibrating object (8). The optical and/or microwave probing signals (20) remotely irradiate an object (8) of interest. The object (8) reflects and/or scatters the probing wave (20) toward a receiver (22). The reflected/scattered modulated signal (24) is received with a remote sensor (receiver) (22). Vibration causes additional phase modulation to the probing wave (20). At the receiving end, the signal is demodulated to extract and analyze the vibration waveform (26, 28). The present invention can be utilized for nondestructive testing, monitoring of technological processes, structural integrity, noise and vibration control, mine detection, etc.

WO 01/14825 A1

FIG. 1

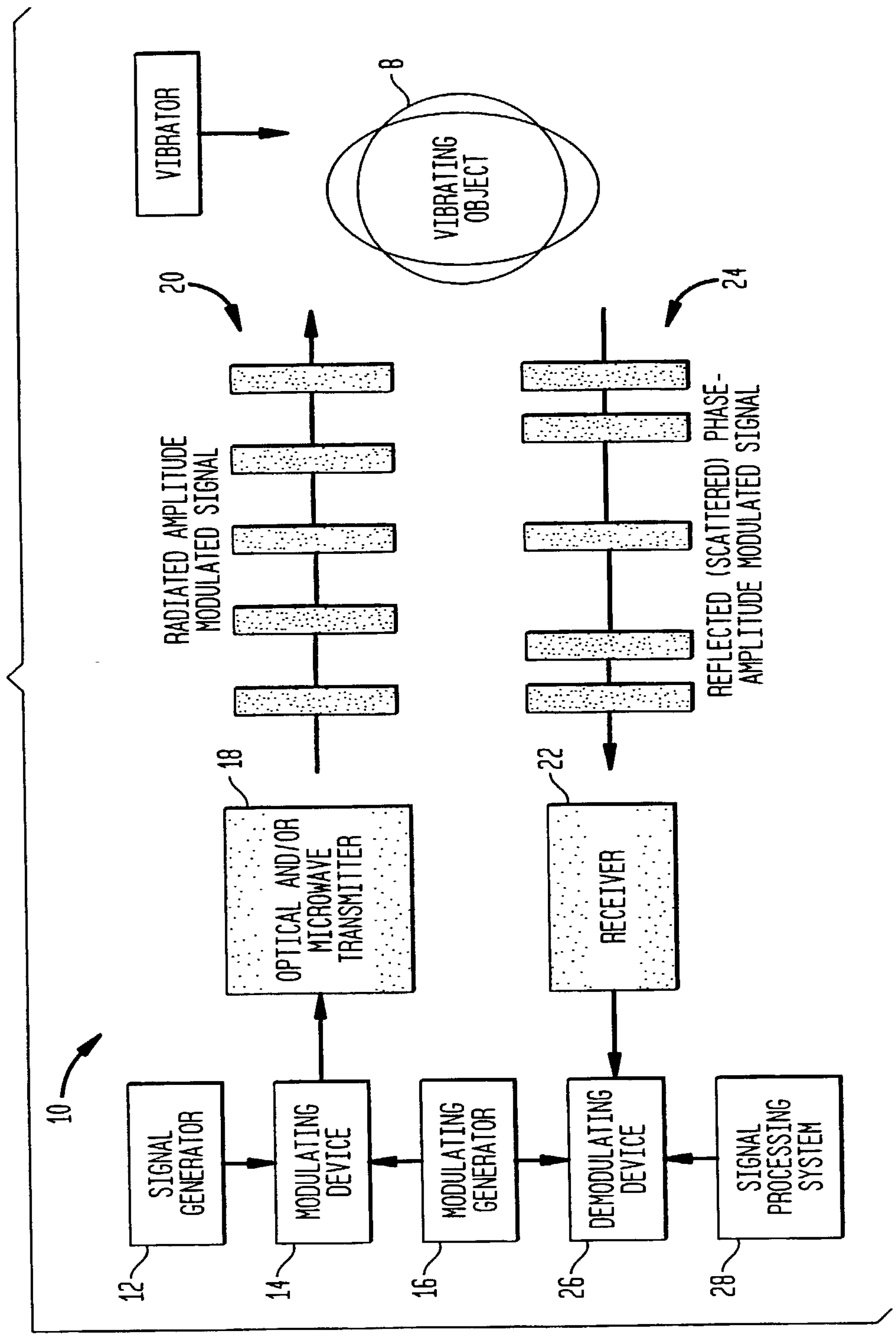
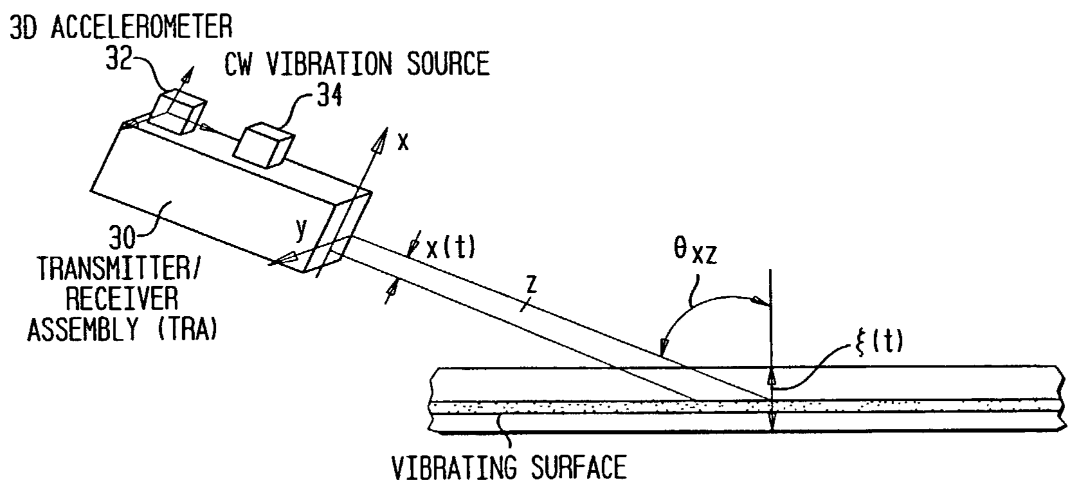

VIBRATOR
VIBRATING OBJECT
8
20
24
RADIATED AMPLITUDE MODULATED SIGNAL
REFLECTED (SCATTERED) PHASE-AMPLITUDE MODULATED SIGNAL
18
OPTICAL AND/OR MICROWAVE TRANSMITTER
22
RECEIVER
10
SIGNAL GENERATOR
MODULATING DEVICE
MODULATING GENERATOR
DEMODULATING DEVICE
SIGNAL PROCESSING SYSTEM
12
14
16
26
28

FIG. 2


3D ACCELEROMETER
32
CW VIBRATION SOURCE
34
x
30
TRANSMITTER/
RECEIVER
ASSEMBLY (TRA)
y
x(t)
z
θxz
ξ(t)
VIBRATING SURFACE

3/4

FIG. 3A

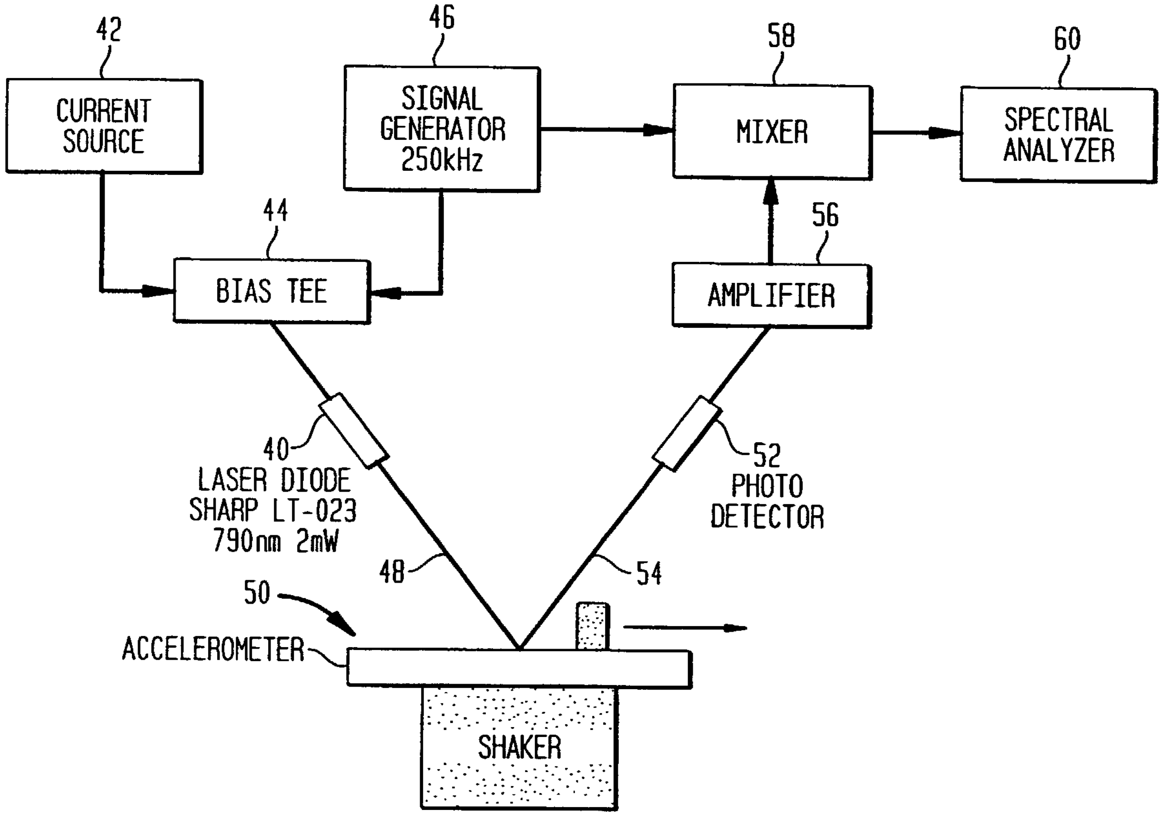


FIG. 3B

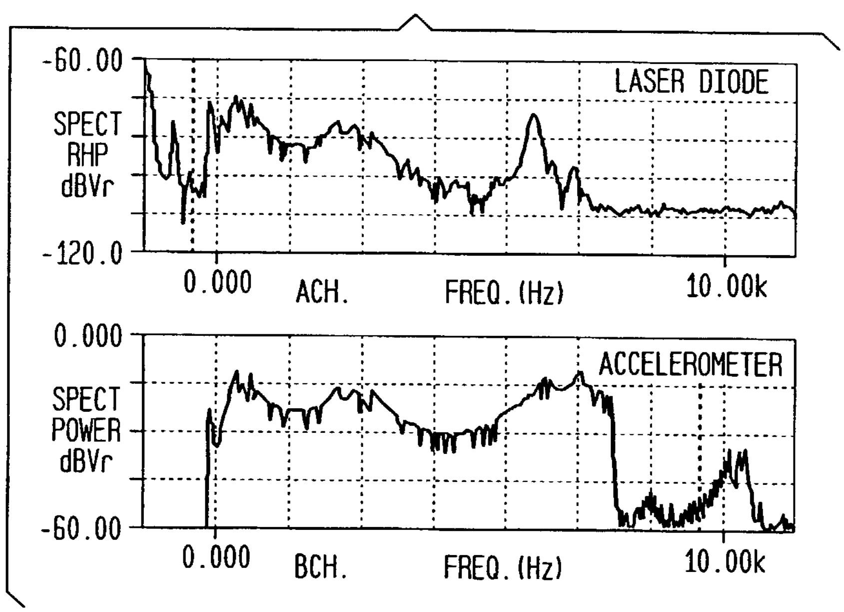
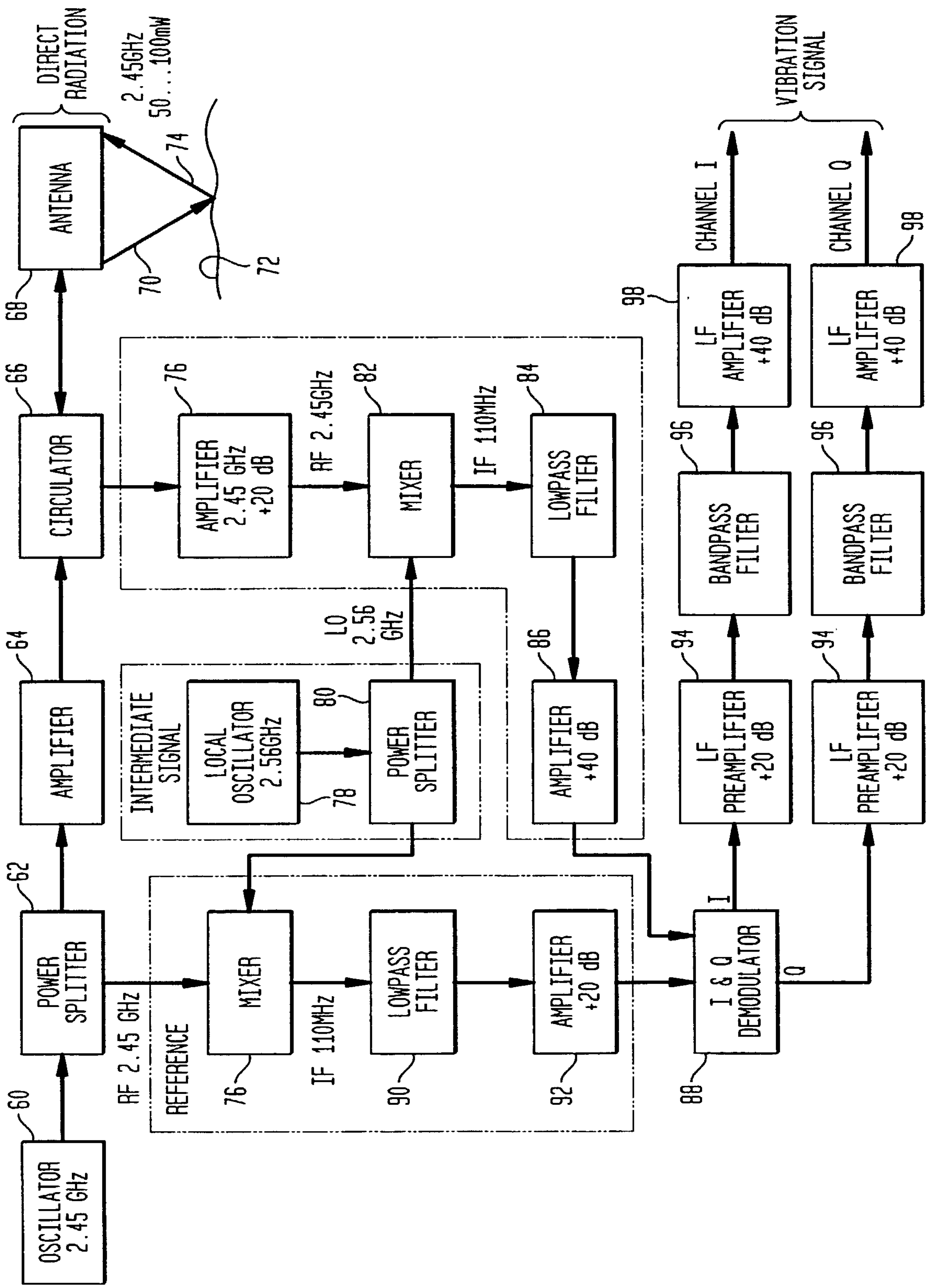


FIG. 4


OSCILLATOR 2.45 GHz
60
POWER SPLITTER
62
AMPLIFIER
64
CIRCULATOR
66
ANTENNA
68
DIRECT RADIATION
2.45GHz 50...100mW
70
72
74
RF 2.45 GHz
REFERENCE
MIXER
76
IF 110MHz
LOWPASS FILTER
90
AMPLIFIER +20 dB
92
INTERMEDIATE SIGNAL
LOCAL OSCILLATOR 2.56GHz
78
POWER SPLITTER
80
LO 2.56 GHz
AMPLIFIER 2.45 GHz +20 dB
76
RF 2.45GHz
MIXER
82
IF 110MHz
LOWPASS FILTER
84
AMPLIFIER +40 dB
86
I & Q DEMODULATOR
88
I
Q
LF PREAMPLIFIER +20 dB
94
BANDPASS FILTER
96
LF AMPLIFIER +40 dB
98
CHANNEL I
CHANNEL Q
VIBRATION SIGNAL

Docket No.
7604/21/1

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
Method and Apparatus for Remote Measurement of Vibration and Properties of Objects

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on 02/20/02 as United States Application No. or PCT International Application Number PCT/US00/23057
and was amended on ______________________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)			Priority Not Claimed
(Number)	(Country)	(Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐
(Number)	(Country)	(Day/Month/Year Filed)	☐

I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

60/150,224	08/23/99
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)
(Application Serial No.)	(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)
(Application Serial No.)	(Filing Date)	(Status) (patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(list name and registration number)*

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Fourth inventor's signature
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Full name of fifth inventor, if any

Fifth inventor's signature
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Full name of sixth inventor, if any

Sixth inventor's signature
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Citizenship

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